Oyster Population Estimation in Support of the Ten-Year Goal for Oyster Restoration in the Chesapeake Bay: Developing Strategies for Restoring and Managing the Eastern Oyster.

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ABSTRACT

The dramatic decline of the eastern oyster, *Crassostrea virginica* (Gmelin, 1791), population in the Chesapeake Bay during the last century has impacted the ecosystem and economy of the region. A collaborative project was initiated between researchers in Maryland and Virginia with the goal of quantifying the baseline oyster population, and establishing the monitoring, data management, and data analysis frameworks for measuring progress toward the Chesapeake 2000 oyster restoration goal of a ten-year, ten-fold increase. Using fishery independent dredge surveys in Maryland, oyster abundance from 1994 to 2002 ranged from 1.60 to 5.55 x 10^8 oysters, with a mean of 4.14 x 10^8 oysters and with a current standing stock of approximately 279,245 bushels. Intensive patent tong surveys in the James River, Virginia between 1993 and 2000 indicate a fairly stable population of 4.41 and 6.30 x 10^8 oysters with a current standing stock of approximately 365,000 bushels. The grand total estimates for the Virginia productive bottoms using both patent tong and dredge data vary from 5.31 x 10^9 to 6.00 x 10^{11} oysters.

INTRODUCTION

The dramatic decline of the eastern oyster, *Crassostrea virginica* (Gmelin, 1791), population in the Chesapeake Bay during the last century has impacted the ecosystem and economy of the region. This decline has reduced the filtration capacity of the oyster population and has caused a shift from a benthic to a pelagic-dominated ecosystem (Baird and Ulanowicz, 1989). Accordingly, the Chesapeake 2000 Agreement established a 10-fold increase in the biomass of the Bay oyster population by 2010 as one of the principal goals of the Bay restoration effort. A collaborative project was initiated between researchers in Maryland and Virginia with the goal of quantifying the baseline oyster population, and establishing the monitoring, data management and data analysis frameworks for measuring progress toward the oyster restoration goal. Two estimators of the size of the oyster population in the Bay were developed as goals, these being the absolute number of oysters, and their biomass. The absolute number is valuable as the index of population size, but it can be misleading in that it varies enormously and does not differentiate between the ecological contribution of a large versus small oyster. In assessing ecological function, oyster biomass is a more useful barometer of population size. Biomass estimates focus on one year and older oysters. Young-of-the-year oysters, or spat, are exposed to high levels of predation. Both their biomass and absolute abundance experience large fluctuations both annually and inter-annually.

Both Maryland and Virginia support oyster fisheries, however the Maryland fishery is almost exclusively a public access fishery while in Virginia there is an historical mix of a direct public access fishery and a private fishery based on leases of bay bottom. Unlike the public fishery in Virginia, the leased private grounds can be planted with spat and harvested throughout the year once they reach the legal marketable size. Landings in Virginia illustrate a long-term decline and are at a level <1% of the historical high of the 1880's (Fig.1). Landings in Maryland have also declined rapidly from historic levels, then stabilized in the early 1990's, but are again in a state of decline (Fig.1). In both states the cumulative impacts of the diseases, MSX (*Haplsporidium nelsoni*) and Dermo (*Perkinsus marinus*) on harvest have been and continue to be substantial. Fishery dependent data contributes to population estimation in Maryland, however, the collapse of the fishery severely limits the use of such data in Virginia.

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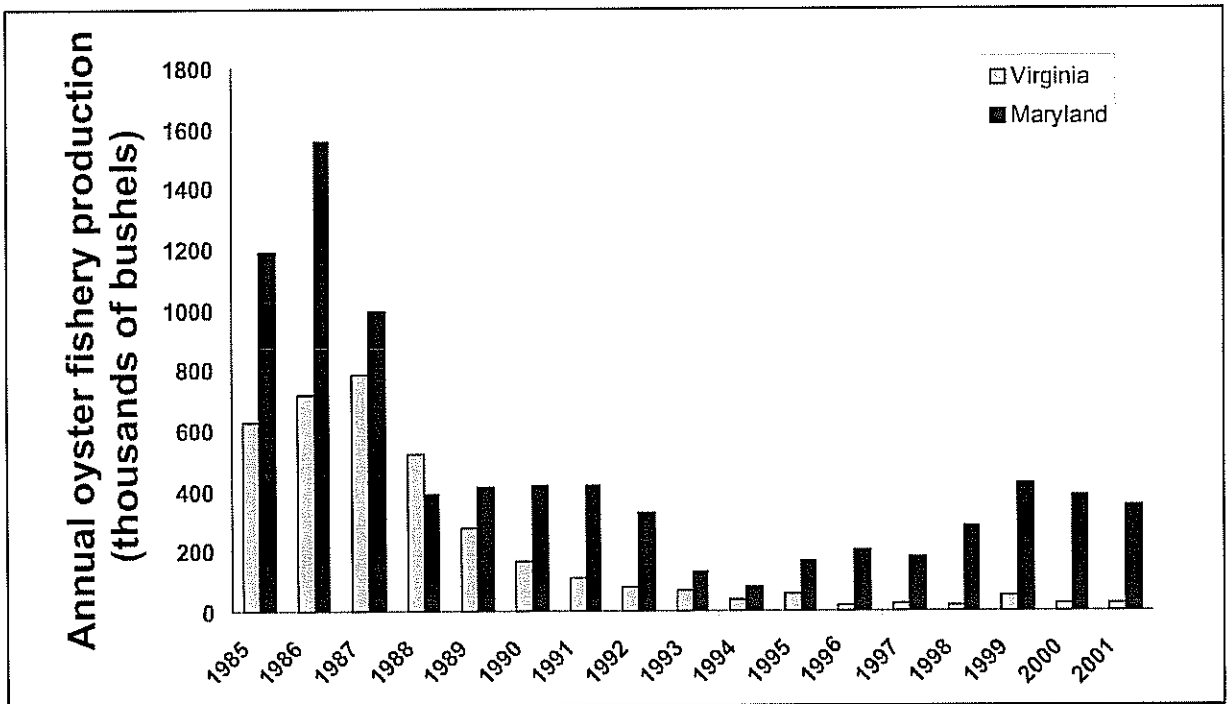

Figure 1. Oyster fishery production from 1985 - 2001.

OBJECTIVES

The past two years have been largely dedicated to developing the framework with which to evaluate the ten-year restoration goal. These objectives included: (1) Examining the extant datasets in MD and VA for their utility in estimating the Chesapeake Bay oyster populations. (2) Developing a compatible, geo-referenced, shared archive of MD and VA data; developing the protocols to provide consistent data acquisition in the future. (3) Identifying sentinel populations to act as proxies for changes in the oyster population. (4) Offering review of emerging restoration efforts. The current project builds off the data produced by MD and VA over the previous two years. The data will be used improve our understanding of oyster population parameters such as growth, recruitment, and natural and fishing mortality, establish biological reference points, and develop the tools with which to evaluate the efficacy of various management options. These continuing objectives are: (1) To quantify the efficacy of various management options for restoring oyster populations. (2) To develop management recommendations based on the most biologically effective combination of options. (3) To develop concise recommendation for managing commercial oyster fisheries consistent with the restoration goals set forward.

METHODS

In Maryland, the Department of Natural Resources conducts an annual modified fall dredge survey at 43 sites that have been used to track changes in the oyster population as well as disease intensity and prevalence from 1990 to present. These were selected because they were representative of the diverse types of oyster bars. Tracking towards the ten-year goal is focused on designated sentinel sites in each state. Sentinel sites are a subset of survey data for which historical data typically exists and for which long term monitoring will continue as part of the 2010 goal evaluation. These sites include both historically well sampled locations and more recent sanctuary and restoration sites. The Maryland dredge survey 43 core sites have been supplemented with four additional sites that are closed to the fishery, and comprise Maryland's sentinel sites. The distance the dredge is towed as well as the total volume of material sampled by the oyster dredge has been measured since 2001. In Spring and Summer 2002, field studies were conducted to determine dredge sampling efficiency within various oyster habitat types. This data, plus additional data to be collected in Spring/Summer 2003, will serve to develop a suite of oyster dredge efficiencies that can be used to estimate the oyster population. To estimate the oyster population prior to 2001, a conversion factor was developed from the dredge track measurements and volumetric samples taken in 2002. In Virginia a combination of long term dredge data covering extensive areas has been combined with more focused patent tong surveys using stratified random sampling designs. The patent tong surveys provide a continuous data series for the James River for the period 1994-present. Slightly shorter time frames are covered for the Great Wicomico and Piankatank Rivers, and more recently extended surveys have been added in the Rappahannock River, as part of the Oyster Heritage Program, and other sites as restoration activities continue. Long term data from the James using both dredge and tong data were examined to develop a conversion function for application in estimating absolute abundance from dredge data. This conversion is the focus of continuing work. Virginia has identified 32 sentinel sites for long term monitoring of progress towards the 2010 goal, these being a combination of both old sites for which data exist, and new sites in recent restoration areas.

Both Maryland and Virginia have reported and archived their data for this project in the common currency of oyster per area. Data has been found to be highly compatible between the two states. In the Maryland dredge survey, the oysters in a one bushel sub-sample are counted and measured to the nearest 5 mm size class. Virginia 's fishery independent data is collected from both dredge and patent tong surveys Virginia fishery independent Size frequency data for oysters measured to the 5mm size class is available from Virginia dredge and patent tong surveys. Size frequency data is being used in a length-based analysis of individual oyster growth. Oyster growth provides an essential link between spat settlement and the fishable stock. In order to evaluate potential oyster management options, it is essential to understand population dynamics and quantify parameter such as growth, fishing and natural mortality, and recruitment. Additionally, size frequency data will be used to estimate natural mortality in Virginia, where harvest is negligible and in Maryland within fishery closures. These data can then be compared to box (articulated oyster shells) counts that comprise present annual mortality estimates in Maryland, but are believed to be biased high due to dead oyster shells that fail to disarticulate within a year. Refined oyster population parameters will then be used within a framework to examine the efficacy of various restoration and management options.

Identification of oyster habitat within Maryland and Virginia remains an important aspect of this project. The incorrect estimate of habitat can result in a gross over or under-estimation of oyster population size within the Bay. The continued incorporation of refined oyster habitat data through acoustic surveys will serve to refine these population estimates as this project continues.

RESULTS

Mean oyster density from fishery independent MD dredge surveys is estimated to range from 1.07 to 2.49 oysters per m^2 in 2002, as estimated using the total population size extrapolated over an estimated area of high and low quality habitat available in the Bay. It should be noted that due to the highly gregarious nature of the oyster, some areas have much higher oyster density and there are large areas that contain low densities or no oysters. In terms of biomass, it is reasonable to assume that the dry tissue weight of an average oyster is 1 g, so the total biomass would be between 1.6×10^5 and 5.5×10^5 kg. These estimates include all small (<76 mm) and market (>76 mm) oysters, but do not include spat. Estimates of the standing stock of market oysters in 2002 were 279, 245 bushels for Maryland. Using fishery independent and dependent surveys, from 1994 to 2002 range from 0.160 to 0.555×10^9 oysters, with a mean of 0.414×10^9 oysters in Maryland. Intensive patent tong surveys in the James River, Virginia between 1993 and 2000 indicate a fairly stable population of 4.41 and 6.30×10^8 oysters with a current standing stock of approximately 365,000 bushels. Depending on location market oysters vary from <1% to 42% of the standing stock by number. By comparing of dredge and patent tong data for the James River for the 1993-2000 period conversion functions have been calculated that allow extrapolation of dredge data for larger spatial areas in other rivers and regions in the Virginia portion of the Bay. The grand total estimates for the Virginia productive bottoms by this method vary from 5.31×10^9 to 6.00×10^{11} oysters and are very sensitive to the conversion function used. Presently productive oyster grounds in Virginia are well below those surveyed by Baylor. The current calculations use only the modest values for high and moderate potential bottom area, as described by Haven et al. (1981); together they constitute only 24.85% of the total Baylor area within the Virginia portion of the Bay. Sub-market (<76mm) size oysters constitute a mean of 79% of the total (spat not included) for the period 1993-2001 in Virginia populations, a much higher percentage than in Maryland. Consequently biomass estimates for oysters in Virginia, which vary from 2.16×10^6 and 2.45×10^8 kg, are comparable to those for Maryland even though Virginia has an estimated higher population.

There is concern for stocks in both states. Young of the year recruitment, commonly termed spatfall, is assessed in both states by fall dredge surveys. Index values represent cumulative recruitment to the benthos and post metamorphic survival to approximately 25mm maximum dimension. In addition, Virginia employs shell string surveys wherein oyster shells, drilled, and strung on wires, are deployed for weekly intervals throughout the summer and early fall months at fixed stations in the subestuaries of the Virginia portion of the Bay that historically demonstrate regular recruitment. Oyster larvae settle and metamorphose onto the shells, and weekly replacement of the shellstrings allows description of the quantities settling within specific time periods in addition to cumulative estimates for the entire year. Unlike the spat index value shell string values indicate potential for benthic recruitment but do not include a post metamorphic mortality component. The Maryland Spat Index follows recruitment at a series of 43 sentinel stations for a period of over 60 years. Recent data illustrate the high inter annual variability in recruitment (Fig. 2). The majority of years since 1986 show values in excess of the long-term median. Indeed six years are above the 75% quartile; however, the past three years are generally between the 25% quartile and median. The comparable Virginia Spat index is given for the past 16 years for 5 stations in the James River and shows slightly higher median and quartile values than the Maryland long term record. Indices within the past decade have generally remained between the 25% and 75% quartile. Both Maryland and Virginia enjoyed high spat indices in 1991, but the 1997 high value in Maryland was not reflected in Virginia where the lowest index in the 16-year record was recorded.

The diseases, MSX (*Haplospridium nelsoni*) and Dermo (*Perkinsus marinus*) remain as threats to oyster populations in both states, and a substantial portion of natural mortality is directly attributable to one or both diseases. VIMS has maintained a disease monitoring program for MSX since 1960. A general trend of increasing maximum prevalence is observed over the 40 year period with intervals of decreased activity in the early 1970s, 1980s, and 1990s. Recent years have been characterized by very high maximal values, so much so that 2001 monitoring was terminated in September with 91% cumulative mortality of the test population. Maryland, which generally observes lower salinity than Virginia across its 43 sentinel sites, has recorded considerably lower MSX prevalence since 1991. This has, however, notably increased above the average in the 2000-2002 period. The cumulative impacts of disease on long term population trends are evident in recent analysis of stock assessment in the Maryland region of the Bay. In the low salinity (<12 ppt) zone populations are moderate and stable in the face of limited disease pressure (MSX is rare and *Perkinsus* only in low intensity). In the mid salinity zone (12-14 ppt) a declining population from 1985 through 1994 was followed by a modest recovery in 1995-1999. By contrast no recovery has been observed in the high salinity zone (>14 ppt) where MSX in enzootic and *Perkinsus* causes consistently high mortality. The Virginia oyster resource is all predominantly in this region.

Current data describe only limited demographics of the populations and do not include broad surveys of oyster condition index that describe meat content for standard size oysters as a proxy for physiological condition. With the definition of sentinel sites for long term monitoring towards the 2010 goal, there is increasing need for better description of oyster physiological condition and condition index data. Current demographics allow estimation of size and possibly age-dependent natural mortality (M). In stable populations, knowledge of M can allow prediction of year strength recruitment in older year classes with the option to effect area management wherein sub-market size class strength, after debiting for M, can facilitate prediction of the harvestable stock (F, fishery mortality) for the subsequent year. However, extensive analysis of historical survey data for sub-market and market oysters, in concert with fishery landings, suggest that sub-market abundance is not a statistically robust predictor of fishery landings in subsequent years. In Virginia, consistent heavy disease pressure has effectively reduced F to near zero values, while M is both spatially and temporally variable depending on salinity and temperature as promoters of disease pressure. The high proportion of sub market sizes in extant populations illustrates the potentially high size and age specific mortality in oysters approaching market size and underscores the limited value of sub-market sizes as a fishery predictor in Virginia

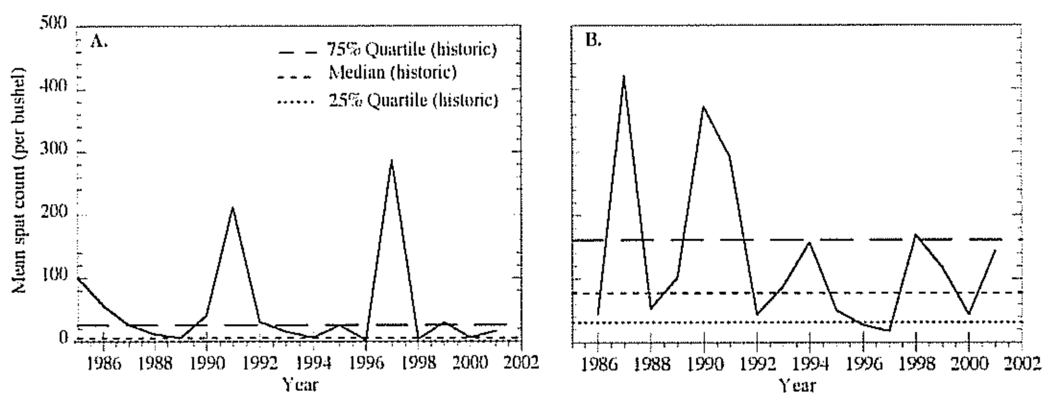

Figure 2. Spat indices based on annual dredge data for Maryland (A) and Virginia (B)

populations. The only stable populations in Virginia, that is populations with minimal disease mortality, are in the low salinity sanctuaries of the upper James River. Estimates for mean annual M values for 1, 2, 3 and 4 year olds are 0.16, 0.19, 0.55 and 0.14 respectively based on transformation of size demography to age demography using unpublished growth data and annual survey data. Estimates can also be made based on ratios of recent mortality, with empty valves or "boxes" as a proxy, to live oysters. Such estimates are slightly problematic because the longevity of intact boxes, as mentioned earlier, is unknown and probably less than one year. This could result in underestimation of M. Robust estimates of M by size class, age class, area and time frame are critical to resource management and are worthy of further study. Current survey records provide a considerable database for the initial stages of this investigation, although supplemental field studies on "box" degradation rates are warranted. Historical data provide a rich environment for examination of underlying population dynamics, although limitations in data collection protocols must be considered.

Management and research recommendations emerging from the project data

Future management would benefit from definition of biological reference points, including over-fishing. A broader goal should include developing a Total Allowable Catch (TAC) for Maryland alone, Maryland and Virginia together as part of a bi-state fishery, Virginia alone, and defined management zones based on salinity as a proxy for disease pressure. Once the above have been completed, evaluation of alternative reference points might provide new options for fishery management. Finally, recognizing the unique value of shell as a habitat limiting resource for oysters, a cost - benefit analysis of various methods of use of the shell resource is suggested. The suggested analysis will provide a framework for evaluation of introduction of oysters with lowered disease susceptibility on the genetic composition of the population in the Bay, with the long impact on estimation of M in the presence of continued disease challenge. Long-term data provide the basis to develop population models, examine possible stock recruit relationships, and examine the sensitivity of management options to variation in M and F. Finally, long term rebuilding of the resource requires continuing knowledge of habitat condition. A promising avenue to update this information on a bay wide basis is to compare spatially referenced patent tong demographic data against high-resolution acoustic surveys in support of total population estimates.

LITERATURE CITED

Baird, D. and R.E. Ulanowicz. 1989. The seasonal dynamics of the Chesapeake Bay ecosystem. *Ecological Monographs* 59:329-364

Calvo, L. and E. Burreson. 2002. Status of the major oyster diseases in Virginia 2001. Annual monitoring report. Virginia Institute of Marine Science, Gloucester Point, Virginia, 23062. VMR 2002-1.

Haven, D. S., J. P. Whitcomb and P. Kendall. 1981. The present and potential productivity of the Baylor Grounds in Virginia. Va. Inst. Mar. Sci., Spec. Rep. Appl. Mar. Sci. Ocean. Eng. No. 243: 1-154.